GROUND PENETRATING RADAR DATA ACQUISITION

PROCEDURE ID: YMP-LBNL-TIP/GP 5.0 | REV. 1, MOD. 0 | EFFECTIVE: 03/20/00

1. PURPOSE

This Technical Implementing Procedure (TIP) describes the process developed to acquire ground penetrating radar data used to investigate the rock and/or soil properties between boreholes, beneath the surface, or other areas not directly accessed with boreholes or excavation. Such an example is the effect of heating on the potential repository rock within the Exploratory Studies Facility (ESF) at the Yucca Mountain Site Characterization Project (YMP), and the monitoring of any resulting moisture redistribution.

2. SCOPE

This procedure applies to all LBNL personnel (or contractor personnel following LBNL procedures) involved in acquiring ground penetrating radar data for the YMP. These activities are subject to requirements of the Quality Assurance Requirements and Description (QARD), DOE/RW-0333P. Prior to conducting work described in Section 3.0 of this procedure, personnel acquiring ground penetrating radar data require training to this procedure.

For all technical activities, data collected using this procedure and any equipment calibrations or recalibrations that may be required shall be in accordance with this TIP and in full compliance with YMP Administrative Procedure (YAP)-12.3Q, *Control of Measuring and Test Equipment and Calibration Standards.* Documentation resulting from actions taken under this TIP shall be recorded in scientific notebooks as described in the Office of Civilian Radioactive Waste Management (OCRWM) Administrative Procedure (AP)-SIII.1Q, *Scientific Notebooks.* Electronic data maintenance, controls and transfers shall comply with YMP-LBNL-Quality Implementing Procedure (QIP)-SV.0, *Control of the Electronic Management of Data.*

If this procedure cannot be implemented as written, YMP-LBNL personnel shall notify the responsible Principal Investigator (PI) or designee. If it is determined that a portion of the work cannot be accomplished as described in this TIP, or would produce undesirable results, that portion of the work shall be stopped and not resumed until this procedure is modified per YMP-LBNL-QIP-5.2, *Preparing Development Plans & Quality /Technical Implementing Procedures*.

If the responsible PI or designee determines that a modification or a revision to the TIP would cause an unreasonable delay in proceeding with the task, then an expedited change to the procedure, including documentation of deviation from the approved procedure, can be made according to YMP-LBNL-QIP-5.2. Such changes

are subject to review, usually after the task has proceeded, and thus work performed under TIPs with expedited changes is done at risk of future invalidation.

Employees may use a controlled electronic or hard copy of this procedure; however, employees are responsible for assuring that the correct revision of this procedure is used. When this procedure becomes obsolete or superseded, it shall be destroyed or marked "superseded" to ensure that this document is not used to perform work.

3. PROCEDURE

3.1 Equipment Description

All radar data are acquired using the Sensors and Software, Inc. pulseEKKO 100 ground penetrating radar system or similar equipment as specified below. The pulseEKKO system consists of six basic components, including a pair of matched antennas, a transmitter electronics unit, a receiver electronics unit, a control console and a personal computer acting as a recording system and data storage unit.

3.2 Component Specifications

3.2.1 Antenna Specifications

The pulseEKKO 100 antennas are resistively damped dipolar antennas. The antenna radiation patterns are the pattern of a half wavelength dipole. Each antenna pair is designed to have a bandwidth to center frequency ratio of one. The borehole antennas have center frequencies of 200, 100 or 50 MHz.

3.2.2 Transmitter Electronics Specifications

The pulseEKKO system used consists of a 1000 volt transmitter having a peak voltage of 1000 volts with a rise time of 2.5 nanoseconds. The 1000V transmitter is typically used with both the 100 and 50 MHz antennas while the 200 MHz antennas perform optimally when utilizing the 400V transmitter. The transmitter is powered by 12 volts and emits a pulse on command from the control console. The power actually radiated from the system is very dependent on the subsurface conditions. The 1000V transmitter used here delivers a peak power of 3.2 kilowatts into a 50 ohm load while the 400V transmitter delivers peak power of 1.5 kilowatts into the same 50 ohm load. Only a small fraction of the available power is actually transformed into a radiated electromagnetic signal

because the antennas are damped and are very inefficient radiators.

3.2.3 Receiver Electronics Specifications

The receiver electronics digitize the voltage at the receiver antenna connector to 16-bit resolution. The receiver design is such that it acquires the received waveform with very high fidelity. The receiver electronics clip the incoming voltage at a 50 mV level and the receiver noise level is nominally around 200 microvolts per stack. The present receiver resolution for a single bit after analog to digital conversion is 1.5 microvolts.

3.2.4 Control Console

The control console provides the overall management of the transmitter and receiver operation. The control console is a microprocessor- controlled unit that communicates with both the transmitter and receiver electronics and the external PC. The PC passes the system configuration information and the acquisition parameters to the control console that then manages all of the hardware functions of the PulseEKKO radar system.

3.2.5 The software used to acquire the data and to run the radar system is the Sensors and Software, Inc. EKKO42 ground penetrating radar executable program. The only software used to evaluate the data is for display purposes and hence is exempt from the requirements of AP-SI.1Q, *Software Management*.

3.3 Operating Principles

The operating principles are as follows:

3.3.1 The Staff Member defines the time window, sampling interval and number of pulses to be stacked via the PC user interface;

3.3.2 The Staff Member selects the acquisition mode;

3.3.3 The PC configures the pulseEKKO console through the PC's standard RS232 port and the console takes over control of data acquisition;

3.3.4 The pulseEKKO console commands the transmitter to fire; the transmitter generates a high voltage pulse which is shaped by the transmitting antenna into a radiated pulse;

3.3.5 The console advises the receiver electronics to digitize the signal from

the receiving antenna; the receiver digitizes the ambient electric field present at the receiving antenna after the band limiting characteristics of the antenna transfer function; the digital number representing the voltage at the time of acquisition is transferred to the control console;

3.3.6 Repeat steps 3.3.4 and 3.3.5 until the parameters specified in Step 3.3.1 are achieved;

3.3.7 The console transmits the stacked waveform to the PC;

3.3.8 The PC stores the data and displays the radar trace.

The information obtained using this procedure shall be documented in a scientific notebook in accordance with AP-SIII.1Q, *Scientific Notebooks*.

3.4 Survey Methodology

The borehole radar technique utilizes a crosshole radar profiling method in which the transmitter and receiver antennas are located in separate boreholes and data are collected with the antennas at various vertical offsets. Staff Members shall collect data using both of the following acquisition modes.

- The first is the Zero Offset Profile (ZOP) in which the transmitting and receiving antennas are fixed such that there was no vertical offset between them.

- The second is the Multiple Offset Profile (MOP) in which the receiving antenna remains at a fixed location while the transmitting antenna is moved incrementally in the second borehole.

3.4.1 The radar data are acquired in two semi-parallel boreholes, one containing the transmitting antenna and the other containing the receiving antenna. Any number of borehole pairs (or drift-to-drift, or borehole-to-drift combinations) can be used. The borehole or drift shall not contain any metal or highly conductive material between the measurement point (i.e. the transmitting antenna) and the receiver point. This will severely attenuate the radar signal. Typically PVC-cased, teflon-cased or uncased boreholes are used. The coordinates defining the location of the boreholes are determined through surveying techniques such that the location of the transmitter and receiver positions within the boreholes can be determined to within approximately 1.0 cm.

3.4.2 To determine accurate travel times between the transmitter and receiver antennas, it is vital to know the precise time at which the

transmitter fires (known as time-zero). The procedure used to determine time-zero for the surveys consists of recording four direct air wave measurements (the signal from transmitting antenna to receiving antenna in air) with the antennas held in air at a separation of 2.0 meters.

3.4.3 After the time-zero data are collected, the antennas are immediately inserted into the boreholes and a ZOP dataset is collected. Another set of four measurements in air at a 2.0 meter separation is then collected upon completion of the ZOP dataset.

3.4.4 Following this procedure, the MOP dataset is collected. As in all MOP gathers, the receiving antenna remains at a fixed location (1m, 1.25m, 1.5m, etc.) in one borehole while the transmitting antenna occupies each of its possible locations along the length of the other borehole. In this manner, all MOP gathers are collected with filenames assigned corresponding to the well pair being surveyed and the fixed receiver location (e.g., MOP10400 - an MOP gather collected for well pair #1 at receiver location 04.00m below the wall surface).

3.4.5 Following MOP acquisition, a final ZOP dataset is collected as described in Section 3.4.2 and 3.4.3. This is done in an attempt to estimate any time-zero drift that may have occurred during the course of the survey. By comparing the two ZOP datasets along with the identical data included in the MOP dataset, any time-zero drift may be compensated for and corrected.

3.5 System Calibration

This section describes the procedures to test the performance of the ground penetrating radar (GPR) system in order to assure that the operation of the system is in accordance with manufacturer's specifications for maximum Peak to Peak Amplitude voltages, as described in Attachment 1.

3.5.1 Standards to be Used

For calibration of Measuring and Test Equipment (M&TE) in accordance with this TIP, the PI or designee shall obtain the M&TE calibration standards pertaining to the GPR system equipment identified in Attachment 1. These standards do not have traceability to recognized standards (e.g. National Institute of Standards and technology [NIST]). The PI shall complete an M&TE Justification Form for the manufacturer's established standards for the GPR system in accordance with YAP-12.3Q. This form shall be filed in the

scientific notebook.

3.5.2 Calibration Method

The method of calibration testing described below ensures that all the major system components described in Section 3.2 are tested in unison. Each must be functioning correctly for the calibration to be successful. Individual components are not tested separately.

A. The GPR system is configured as described in Section 3.3. The transmitter voltages and antenna frequencies to be tested are:

- Transmitter Voltages:
  400 V (200 MHz antenna)
  1000 V (100 and 50 MHz antennas)

- Antenna Frequencies:
  50 MHz
  100 MHz
  200 MHz

B. The radar antennas to be used (200, 100, 50 MHz) are then located upright in air at fixed distance intervals (10.0 meters for the 200 and 100MHz antennas; 25.0 meters for the 50MHz antennas). The antenna separation is recorded in the scientific notebook.

C. The transmitter electronics unit to be used (400 volt unit for the 200MHz antennas; 1000 volt unit for the 100 and 50MHz antennas) is then fired repeatedly, and the received radar waveform is monitored on a calibrated oscilloscope.

D. The received waveform is then evaluated as to the amplitude and waveform characteristics and the results are recorded in the scientific notebook. These results are compared with the values and acceptable tolerances from the manufacturer's specifications (Attachment 1) for the test in question. The Staff Member notes whether the data for a particular test are acceptable or unacceptable.

F. If the results for all the necessary tests are acceptable (meet manufacturer's specifications within specified tolerances), The Staff Member records in the scientific notebook a statement of acceptability to complete the documentation of the calibration. In addition, a "M&TE Calibration Sticker" is prepared containing the word "CALIBRATION", Staff Member name, date the tests were performed, due date next calibration needed, and a unique

identification of all the GPR components tested. This Calibration Sticker is affixed in a location proximate to the Control Console.

3.5.3 Equipment Storage and Handling

In order to ensure long-term compliance, the GPR System should be considered to be a delicate/fragile electronic apparatus. As such, it should be handled with care and stored in such a way as to minimize any harsh environment conditions (e.g. excessive temperature, moisture or vibration).

3.5.4 Identification of Tolerances and Range of Use

The tolerances and range of use for the GPR system have been specified by the manufacturer and included in Attachment 1.

3.5.5 Calibration Intervals

This calibration test shall be performed annually. All calibration results shall be recorded in the scientific notebook and forwarded to the RPC, pursuant to YAP-12.3Q. In addition, a "M&TE Calibration Sticker" document shall be prepared and located in proximity to the Control Console.

3.5.6 Documentation

For each test, the following information shall be recorded in the scientific notebook:

- Unique identification of all the GPR components used
- Date calibrated
- Calibration Data (i.e., actual test results)
- Recalibration due date or calibration interval/frequency
- Procedure (including revision level) used to calibrate the M&TE
- Identification of and traceability to the calibration standards used for the calibration
- Results of the calibration and the statement of acceptability based on manufacturer's specifications

- As-found condition of the M&TE, as appropriate

- Specified range and tolerances and whether the M&TE met those tolerances

- Personnel performing calibration must add reference to any actions taken with out-of-calibration or nonconforming M&TE, including evaluation results, as appropriate (see Section 3.6 below)

The M&TE Calibration Documentation Form (Attachment 2) may be used to document the above. If used, it shall be filed in the scientific notebook. Copies of the calibration results shall be provided to the M&TE Coordinator to update the M&TE list as per YAP-12.3Q.

3.6 Control of Out-of-Calibration Conditions

3.6.1 If the results of any of the tests are not acceptable, the GPR system shall be considered out-of-calibration. The system shall be removed from service and designated out-of-service until repaired. Nonconforming or out-of-tolerance equipment shall be segregated or tagged with an Out-of-Service tag in accordance with YAP-12.3Q and not be used. Recalibration shall be attempted to remedy the nonconformance. This may require that the system be returned to the manufacturer for repair and recalibration.

3.6.2 All data acquired from the out-of-calibration GPR system during the period of time from the date of last successful calibration to the out-of-service date shall be flagged or marked accordingly as suspect, and subject to further processing to determine its validity and ensure that it meets the compliance requirements. No data shall be collected in support of the test until the GPR system is returned to calibrated status.

3.6.3 Recalibration when updates to software affects calibration:

Not applicable.

3.6.3 Staff Member shall document each usage of the equipment in the scientific notebook or on the M&TE Standard Usage Log as described in YAP-12.3Q and file the form in the scientific notebook.

4. RECORDS

4.1 Lifetime

Records generated as a result of this TIP are entries in scientific notebooks or attachments to such notebooks and the electronic data files associated with these entries.

4.2 Non-Permanent

None

4.3 Controlled Documents

Technical Implementing Procedure (TIP)

4.4 Records Center Documents

Records associated with this procedure shall be submitted to the Records Coordinator for transmittal to the Records Processing Center (RPC) in accordance with AP-17.1Q, *Record Source Responsibility for Inclusionary Records*.

5. RESPONSIBILITIES

5.1 The Principal Investigator (PI) is responsible for assuring full compliance with this procedure and providing training thereof. The PI is responsible for overseeing and coordinating TIP preparation, review, distribution, revision, and recommended of rescission.

5.2 Staff Members involved in GPR acquisition activities are responsible for following this procedure and turning over related documentation to the Records Coordinator for submittal to the RPC in accordance with AP-17.1Q. Related data shall be turned over to Technical Data Coordinator for submittal to YMP Technical Data Management System (TDMS) in accordance with AP-SIII.3Q, *Submittal and Incorporation of Data to the Technical Data Management System*.

6. ACRONYMS AND DEFINITIONS

6.1 Acronyms

AP	Administrative Procedure
ESF	Exploratory Studies Facility
GPR	Ground Penetration Radar
LBNL	Lawrence Berkeley National Laboratory

MOP	Multiple Offset Profile
M&TE	Measuring and Test Equipment
NIST	National Institute of Standards and Technology
PI	Principal Investigator
QIP	Quality Implementing Procedures
RPC	Records Processing Center
TIP	Technical Implementing Procedure
TDMS	Technical Data Management System
YAP	YMP Administrative Procedure
YMP	Yucca Mountain Site Characterization Project
ZOP	Zero Offset Profile

6.2 Definitions

None

7. REFERENCES

AP-17.1Q, *Record Source Responsibility for Inclusionary Records*

AP-SI.1Q, *Software Management*

AP-SIII.1Q, *Scientific Notebooks*

AP-SIII.3Q, *Submittal and Incorporation of Data to the Technical Data Management System*

DOE/RW-0333P, *Quality Assurance Requirements and Description (QARD)*

YAP-12.3Q, *Control of Measuring and Test Equipment and Calibration Standards*

YMP-LBNL-QIP-5.2, *Preparing Development Plans & Quality/Technical Implementing Procedures*

YMP-LBNL-QIP-SV.0, *Control of the Electronic Management of Data*

8. ATTACHMENTS

Attachment 1 Statement of Calibration and Acceptable Amplitudes and Tolerances for the Sensors and Software, Inc. pulseEKKO 100 Ground Penetrating Radar System

Attachment 2 The M&TE Documentation Form

9. REVISION HISTORY

09/30/98 Revision 0, Modification 0:

This is the initial issue of this procedure. Derivative of a scientific notebook procedure/methodology prepared by K. Williams and reviewed by Y. Tsang as part of the scientific notebook YMP-LBNL-YMT-ELM-1.1.1.

03/03/00 Revision 1, Modification 0:
Revised procedure to incorporate YAP-12.3Q requirements and references to other applicable APs, YAPs and QIPs. Added Attachment 1, Statement of Calibration and Compliant Amplitudes and Tolerances for the pulseEKKO 100 GPR and Attachment 2, the M&TE Documentation Form. Deleted responsibilities for staff members not directly responsible for implementing this procedure and references to vendor manuals.

10. APPROVAL

Signature on file	
Preparer: Ken Williams	Date
Signature on file	
Technical Reviewer: John Peterson	Date
Signature on file	
Technical Reviewer/PI: Ernest L. Majer	Date
Signature on file	
EA Reviewer: Nancy Aden-Gleason	Date
Signature on file	
OQA Concurrence: Stephen D. Harris	Date
Signature on file	
Project Manager: Gudmundur G. Bodvarsson	Date

Statement of Calibration and Compliant Amplitudes and Tolerances for the pulseEKKO 100 Ground Penetrating Radar System

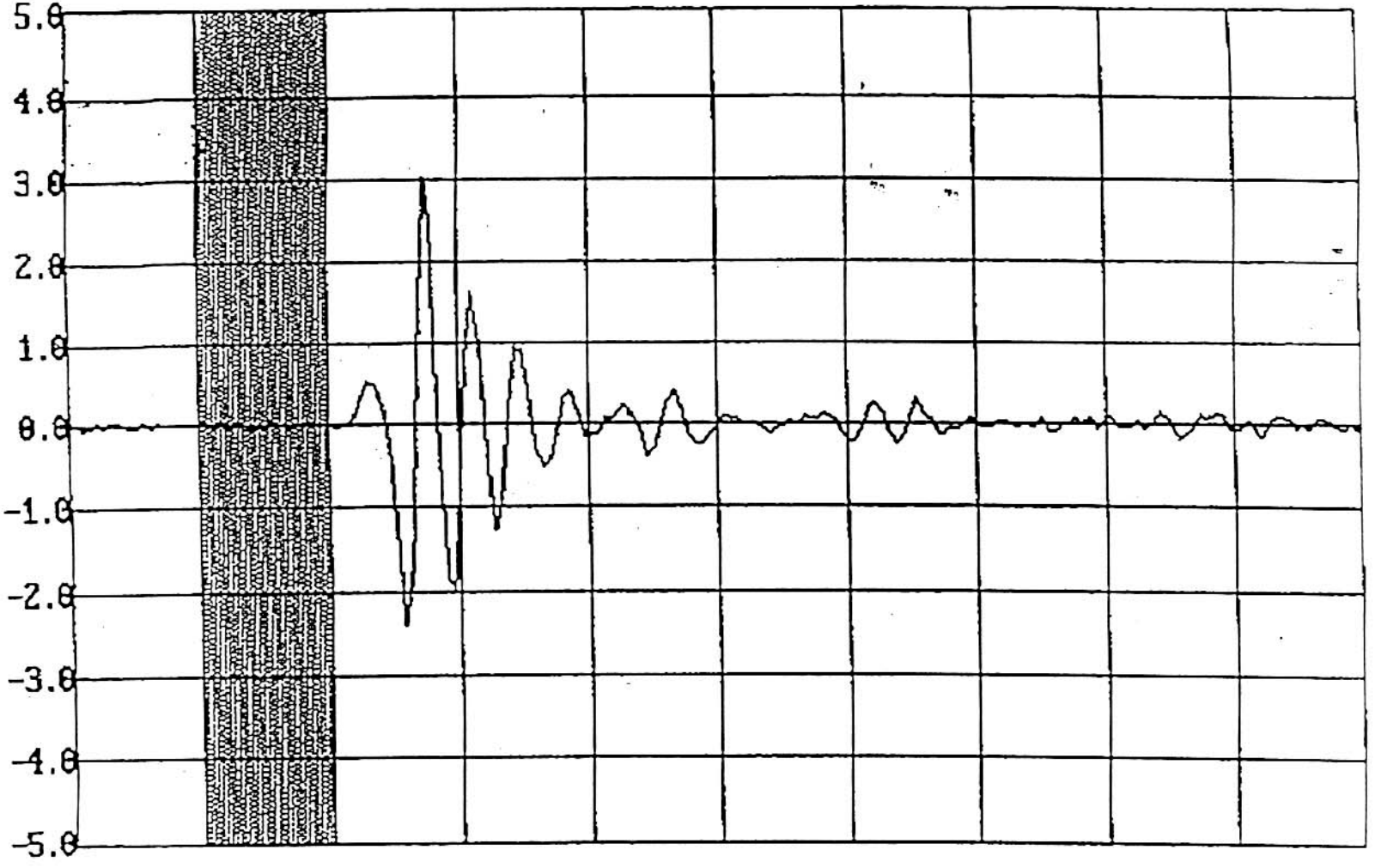
1. Manufacturer's Statement of Compliance and Specifications for Peak to Peak Amplitudes for Following System Parameters:

   a. 200 MHz Borehole Antennas in Air at 10.0 meter Separation Utilizing 400V Transmitter
      - Maximum Peak to Peak Amplitude of 5.4 mV +/- 10%

   b. 100 MHz Borehole Antennas in Air at 10.0 meter Separation Utilizing 1000V Transmitter
      - Maximum Peak to Peak Amplitude of 52 mV +/- 10%

   c. 50 MHz Borehole Antennas in Air at 25.0 meter Separation Utilizing 1000V Transmitter
      - Maximum Peak to Peak Amplitude of 63 mV +/- 10%

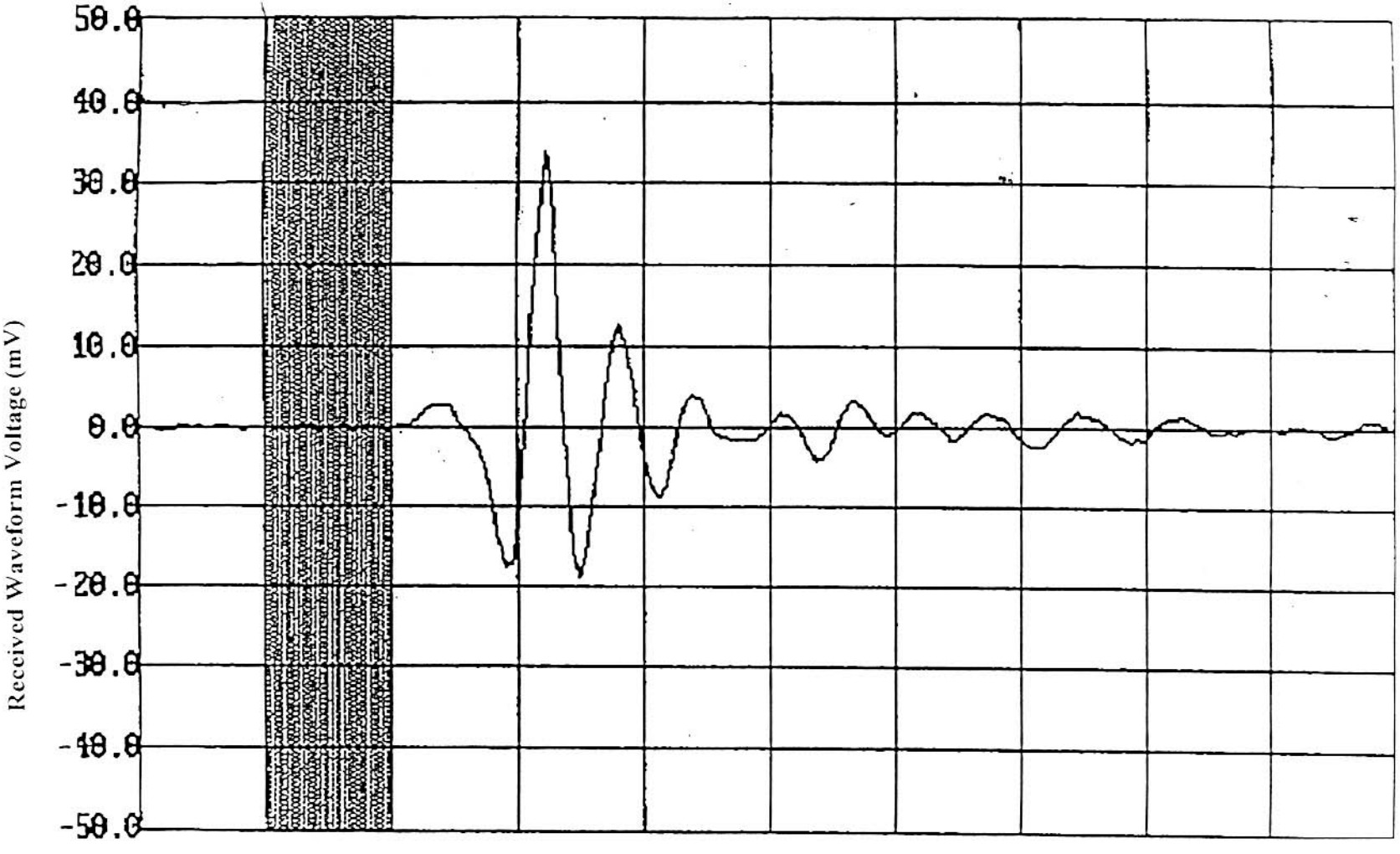
200MHz Borehole Antennas in Air at 10.0m Separation Using 400Volt Transmitter



Time Scale (ns) – Each Interval Represents 10.0 ns of Time

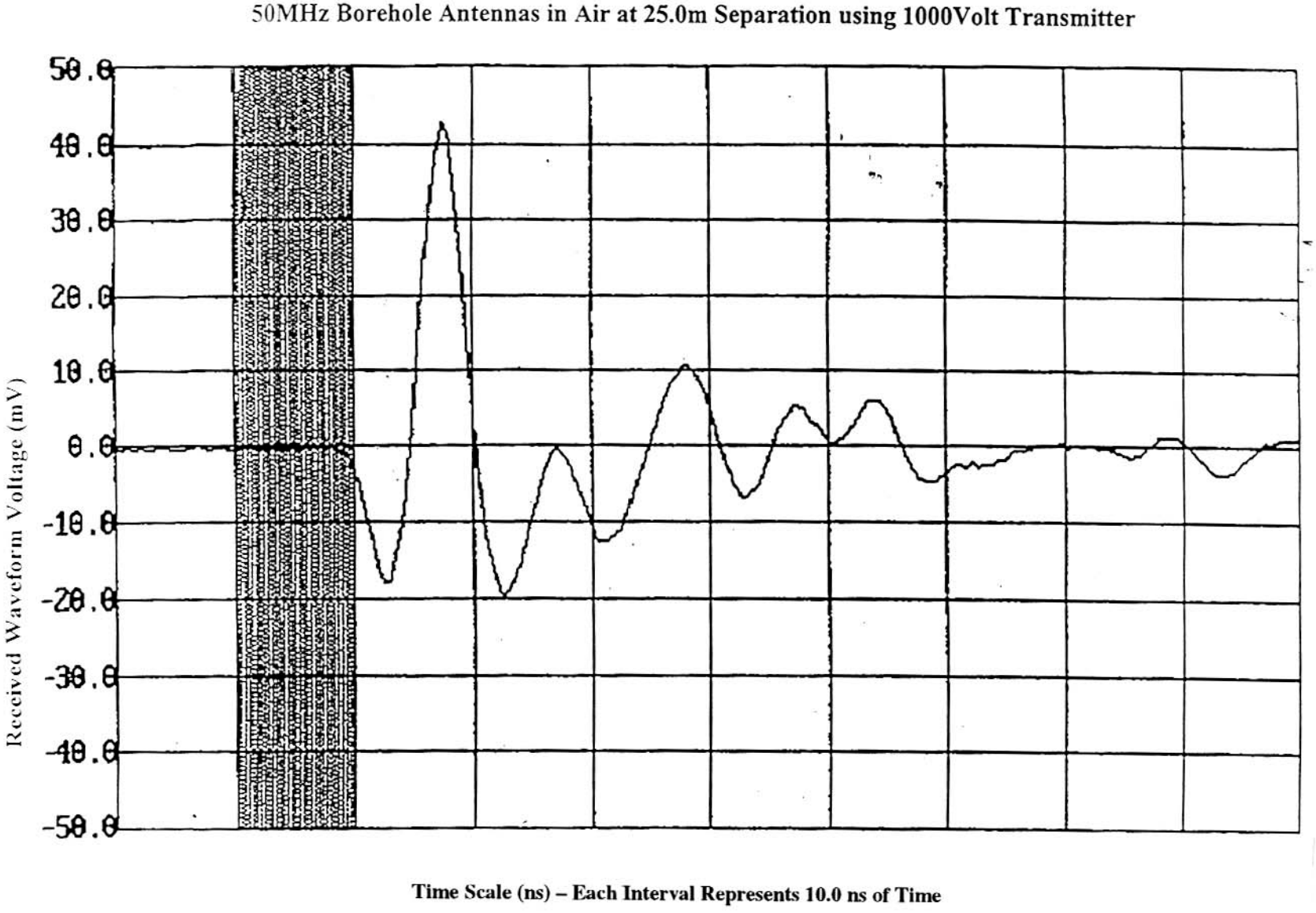
1.1 Waveform Characteristics for a Compliant GPR System Utilizing Setup from 1.a

100MHz Borehole Antennas in Air at 10.0m Separation using 1000Volt Transmitter



Time Scale (ns) – Each Interval Represents 10.0 ns of Time

1.2 Waveform Characteristics for a Compliant GPR System Utilizing Setup from 1.b



1.3 Waveform Characteristics for a Compliant GPR System Utilizing Setup from 1.c

Measuring and Test Equipment (M&TE) Calibration Documentation Form

<table>
<tr><td>a) M&TE Description</td><td>b) M&TE Unique Identification</td><td>c) Calibration Date and Time (if applicable)</td></tr>
<tr><td colspan="2">d) Person Performing Calibrations</td><td>e) M&TE Condition (As-Found)
Working _____

Not Working _____</td></tr>
<tr><td colspan="2">f) Calibration Procedure (including revision level)</td><td>g) Calibration Standards Used</td></tr>
<tr><td colspan="2">h) Location of Calibration Data

YMP-LBNL-_____
Page(s)</td><td>i) Location of Calibration Results

YMP-LBNL-_____
Page(s)</td></tr>
<tr><td colspan="3">j) Statement of Acceptability including Acceptability of Range and Tolerances
Range Acceptable Yes _____, No _____
Tolerance Acceptable Yes _____, No _____
Calibration Acceptable Yes _____, No _____
Comment:</td></tr>
<tr><td colspan="3">k) Specified Range and Tolerances</td></tr>
<tr><td colspan="2">l) Re-calibration due date or calibration interval/frequency</td><td>m) Reference to actions taken with out-of-calibration or non conforming M&TE, including evaluation results, as appropriate

YMP-LBNL-_____
Page(s)</td></tr>
<tr><td colspan="3">n) Comments</td></tr>
</table>

Signature Date